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FATIGUE AND WORKLOAD IN FOUR-MAN C-5A COCKPIT CREWS (VOLANT GAL--ETC(U)

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USAF SCHOOL OF AEROSPACE MEDICINE
Aerospace Medical Division (AFSC)
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NOTICES

This final report was submitted by personnel of the Crew Performance Branch, Crew Technology Division, USAF School of Aerospace Medicine, Aerospace Medical Division, AFSC, Brooks AFB, Texas, under job order 7930-10-32.

When U.S. Government drawings, specifications, or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or supplied the said drawings, specifications, or other data is not to be regarded in any way by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The operational personnel who participated in this study were fully briefed on all procedures prior to participation in the study.

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

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Triple Inertial Navigation Systems (INS) are being installed on C-5A aircraft. At the request of the USAF Airlift Center, aircrew fatigue and workload were evaluated in 4-man C-5A cockpit crews (aircraft commander, copilot, and 2 flight engineers) performing typical long-range transport missions on triple-INS-equipped aircraft. Most of the navigator's duties were assumed by the pilots with the balance assigned to the flight engineer station. Considering subjective fatigue and workload findings, discussions with crewmen, the workloads reported during emergencies and aerial refuelings, and the operational -

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requirements of wartime conditions, it was recommended that the 4-man C-5A crew concept not be implemented at this time.

PREFACE

The authors would like to recognize the outstanding assistance in field data collection provided by Mr. Patrick J. Dowd, Capt Charles A. Flick, Capt Stephen F. Gray, Capt Don L. Makalous, and Capt Layne P. Perelli. Sgt Robin G. Chavez, A1C Vabian L. Paden, and MSgt Paul W. Petty processed and reduced the raw data. Mr. Richard C. McNee of the Data Sciences Division directed the statistical analyses.

Special thanks are extended to the participating crewmen of the 60th Military Airlift Wing, Travis AFB CA. These crewmen enthusiastically supported and participated in the VOLANT GALAXY biomedical evaluation. Their professionalism contributed significantly to the operational validity of the findings.

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FATIGUE AND WORKLOAD IN FOUR-MAN C-5A COCKPIT CREWS (VOLANT GALAXY)

INTRODUCTION

Triple Inertial Navigation Systems (INS) are currently being installed on C-5A aircraft. Because the triple INS is extremely reliable, Headquarters Military Airlift Command (HQ MAC) directed that the USAF Airlift Center conduct an operational test and evaluation (VOLANT GALAXY OT&E) to determine if a 4-man cockpit crew (aircraft commander, copilot, and 2 flight engineers) can successfully perform required missions on triple-INS-equipped C-5A aircraft. Presently, the basic C-5A cockpit crew is comprised of 5 crewmen: 2 pilots, 2 flight engineers, and 1 navigator. Under the 4-man concept most of the navigator duties are assigned to the aircraft commander and copilot positions. The navigator duties not assigned to the pilots are assigned to the flight engineer station.

At the request of the USAF Airlift Center, the Crew Performance Branch of the USAF School of Aerospace Medicine (USAFSAM/VNE) assisted in the VOLANT GALAXY evaluation of aircrew fatigue and workload. An initial version of this USAFSAM report was prepared for inclusion as an annex to the USAF Airlift Center's VOLANT GALAXY Final Report (11).

METHOD

VOLANT GALAXY test flights were conducted at the 60th Military Airlift Wing (MAW), Travis AFB CA, in April and May 1979. A test cadre of five, 4-man crews flew INS-modified C-5A aircraft on representative MAC routes. Pilots selected to participate had accumulated no more than the average C-5A flying time for their crew position. The flight engineers selected for the test crews represented a cross-section of C-5A experience. Prior to the start of the VOLANT GALAXY test, all test members were trained, qualified, and current in INS and aerial refueling (AR) operations. Additional training was conducted in revised procedures for a 4-man cockpit crew.

The Airlift Center requested that 2 MAC observers fly on each test mission. An INS-qualified, C-5A navigator/safety observer was required to be present on each test mission. When the mission included an aerial refueling, the navigator/safety observer had to also be air refueling-qualified. The second test observer was usually a C-5A flight examiner or instructor pilot. In addition to their flight-safety functions, the MAC test observers evaluated the 4-man cockpit aircrew operations and procedures during each test mission.

During May 1979, USAFSAM personnel collected aircrew self-ratings of fatigue and workload throughout 4 VOLANT GALAXY test missions involving 4 different test crews. Additionally, in July 1979, these data were collected during 3 nontest missions flown on triple-INS-equipped aircraft by qualified 5-man crews incorporating a navigator. The intent of USAFSAM was that these 3 standard MAC channel missions would serve as "control" missions for comparison of the findings from the 4 test missions. Every attempt was made to select

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control missions which were replications of the test-mission itineraries, but with a navigator assigned to each crew.

Summaries of the scheduled itineraries and mission logs for each of the 7 missions observed by USAFSAM personnel are presented in Tables A-1 to A-7, Appendix A: Tables A-1 to A-4 summarize the 4 test missions (missions #1-4); Tables A-5 to A-7 summarize the 3 control missions (missions #5-7). Enroute events having major impact on mission schedule and itinerary are identified in each table. Not identified are the dozens of frustrating minor delays related to ground transportation, maintenance problems, passenger processing, and cargo transfer which typically occurred on each mission.

All of the VOLANT GALAXY missions originated and terminated at Travis AFB CA. Two of the test missions (missions #1 and #3) were westbound and return and 2 (missions #2 and #4) were eastbound and return. Aerial refuelings were scheduled for both of the westbound missions, but not for the eastbound missions. Aerial refueling was completed successfully on mission #1. Tanker rendezvous was successful on mission #3, but mechanical problems prevented completion of the aerial refueling, resulting in the only inflight diversion during the 7 missions. By changing a scheduled crew-rest point to a quick-stop, the last 2 scheduled legs of mission #3 were combined into an extended duty day. To proceed in accordance with regulations, a rested pilot augmented the crew at this point and flew most of the final leg. Therefore, the fatigue and workload data collected from the basic test crew during the final leg were not valid and were excluded from analyses. During mission #4, a maintenance problem discovered during preflight required that the crew return to crew-rest status.

Despite the diligent efforts of the MAC project officers, there were considerable differences between the test-mission and control-mission itineraries. The 3 control missions consisted of 1 eastbound (mission #5) and 2 westbound (missions #6 and #7) missions. A scheduled aerial refueling was successfully completed on mission #7. Delays resulting from major maintenance problems occurred once each on all 3 control missions: maintenance problems discovered during preflight resulted in the crews returning to crew-rest status during missions #5 and #7; on mission #6, a landing gear retraction malfunction required immediate return-to-base following takeoff, with the crew subsequently returning to crew rest.

During each preflight interval, usually shortly after show time, each of the crewmen completed a Crew Status Checkcard (SAM Form 219; Fig. 1) and a Subjective Fatigue Checkcard (SAM Form 136; Fig. 2). While airborne, the crewmen completed the Crew Status Checkcard on an hourly schedule. At every fourth hour, they also completed a Subjective Fatigue Checkcard. If asleep, crewmen were not awakened for administration of the USAFSAM checkcards. Within the hour following each landing, each crewman again completed both checkcards.

CREW STATUS CHECKCARD

NAME	DATE/TIME

SUBJECTIVE FATIGUE

INSTRUCTIONS: Circle the number of the statement which describes how you feel RIGHT NOW.

1.	FULLY ALERT; WIDE AWAKE; EXTREMELY PEPPY
2.	VERY LIVELY; ENERGETIC; NOT AT PEAK, BUT VERY REFRESHED
3.	QUITE FRESH; RESPONSIVE; INDUSTRIOUS
4.	OKAY; TYPICAL; SOMEWHAT FRESH
5.	A LITTLE TIRED; LET DOWN; LESS THAN FRESH
6.	EXTREMELY TIRED; FADING; VERY DIFFICULT TO CONCENTRATE
7.	COMPLETELY EXHAUSTED; UNABLE TO FUNCTION EFFECTIVELY; READY TO DROP

WORKLOAD ESTIMATE

INSTRUCTIONS: Circle the number of the statement which best describes the MAXIMUM workload you experienced during the PAST HOUR. Estimate and record the number of MINUTES during the past hour you spent at this workload level.

	1.	NOTHING TO DO; NO SYSTEM DEMANDS
	2.	LITTLE TO DO; MINIMUM SYSTEM DEMANDS; PASSIVE MONITORING
	3.	ACTIVE INVOLVEMENT REQUIRED; EASY TO KEEP UP
	4.	CHALLENGING, BUT MANAGABLE
	5.	PRESSED; VERY BUSY BUT ABLE TO KEEP UP
	6.	OVERLOADED; TOO MUCH TO DO; POSTPONING SOME TASKS; HIGH CHANCE OF ERROR
	7.	UNMANAGABLE; POTENTIALLY DANGEROUS; UNACCEPTABLE

SAM FORM MAY 79 219 (ONE TIME ONLY) Place Comments on Reverse

Figure 1. On each mission leg each crewman completed a Crew Status Checkcard (SAM Form 219) during preflight, at approximately 1-hour intervals while airborne, and within 1 hour after landing.

The Crew Status Checkcard is a recently developed USAFSAM survey for use in field evaluations of crew fatigue and workload. It consists of two, 7-point forced-choice scales. The fatigue scale directs the crewman to identify which statement best describes how tired he feels at that point in time. At the extremes of the subjective fatigue scale, a complete absence of fatigue ("fully alert; wide awake; extremely peppy") is scored as 1 while a feeling of exhaustion ("completely exhausted; unable to function effectively; ready to

drop") is scored as 7. The workload scale directs the crewman to select the statement which best describes the maximum workload he has experienced during the past hour. At the low end of the scale, a no-workload situation ("nothing to do; no system demands") receives a score of 1; at the upper end of the scale, an unmanageable workload ("unmanageable; potentially dangerous; unacceptable") is scored as 7. Responses to workload statements 5, 6, and 7 reflect varying degrees of high workload.

NAME AND GRADE			TIME/DATE
INSTRUCTIONS: Make one and only one (√) for each of the ten items. Think carefully about how you feel RIGHT NOW.			
STATEMENT	BETTER THAN	SAME AS	WORSE THAN
1. VERY LIVELY			
2. EXTREMELY TIRED			
3. QUITE FRESH			
4. SLIGHTLY POOPED			
5. EXTREMELY PEPPY			
6. SOMEWHAT FRESH			
7. PETERED OUT			
8. VERY REFRESHED			
9. FAIRLY WELL POOPED			
10. READY TO DROP			

PREVIOUS EDITION WILL BE USED

SAM FORM SEP 76 136 SUBJECTIVE FATIGUE CHECKCARD

Figure 2. On each mission leg each crewman completed a Subjective Fatigue Checkcard (SAM Form 136) during preflight, at approximately 4-hour intervals while airborne, and within 1 hour after landing.

The Subjective Fatigue Checkcard (8) has been used successfully to evaluate crew fatigue in a wide variety of USAF operational environments. In particular, a large MAC data base has been developed for this checkcard during previous studies such as Operation Cold Shoulder (4, 6) and operational tests of inflight crew rest (7, 9). Crew responses to this checkcard have been systematically related to sleep loss, extended duty periods, circadian rhythms, environmental stresses, and rest and recovery. The Subjective Fatigue Checkcard results in a score ranging from 0-20 (arbitrary units) with lesser scores indicating self ratings of greater fatigue. In general, scores of 12 and

above indicate feelings of alertness, scores of 11 down to 8 suggest moderate fatigue, and scores of 7 and lower indicate severe fatigue. It should be noted that this scoring procedure is the opposite of that for the Crew Status Checkcard, where lower scores indicate less fatigue. Administration of the Subjective Fatigue Checkcard during the VOLANT GALAXY test and control missions not only provided a means of validating the fatigue scores reported on the newer Crew Status Checkcard, but contributed contemporary information and continuity to the MAC data base.

In addition to the checkcard data collected by USAFSAM personnel, an effort was made to document the time devoted by each pilot to selected cockpit activities. A portable, cassette tape recorder was modified and interfaced with a multiple-input switch unit. Each input was assigned a cockpit activity and the USAFSAM observers activated the appropriate switches as the selected activities occurred. An internal clock permitted the timing of each switch activation.

The composition of the 4-man crews flying the 4 VOLANT GALAXY test missions was well defined in terms of USAFSAM data collection. However, because of necessary operational and training considerations, the composition of the aircrews flying the 3 control missions was not always well defined, especially in terms of USAFSAM data collection. The aircrew composition on each of the control missions was greater than a standard 5-man basic cockpit crew. Mission #5 involved 3 qualified pilots, 3 qualified navigators, and 4 (2 qualified, 2 unqualified) flight engineers. USAFSAM data were collected from all the pilots and navigators and the 2 unqualified flight engineers, since 1 of the 2 of them was on-station most of the time. The mission #6 aircrew consisted of the basic crew complement of 2 pilots and 1 navigator, but included 3 qualified flight engineers. Mission #7 was flown by a highly experienced crew composed primarily of USAF Reservists: 3 qualified pilots, 2 qualified navigators, and 3 qualified flight engineers. However, at USAFSAM request, 1 pilot and 1 navigator limited their active participation in this mission. The flying experience of the pilots actively involved in each mission is presented in Table 1.

RESULTS

Subjective Fatigue

The mean Subjective Fatigue Checkcard (SAM Form 136) scores for the pilots and flight engineers during each of the 7 missions were typical of those previously observed during other USAFSAM and MAC studies of long-range transport operations (4, 6, 7, 9). These data are presented graphically in the upper panels of Figures B-1 to B-14, in Appendix B. For each leg of each mission, the crewmen reported well rested for preflight, feeling fresh and alert. On the average, feelings of fatigue gradually increased as each leg progressed, attaining moderate but not severe levels at the termination of legs occurring during the latter half of a mission. The findings for the Crew Status Checkcard scores (SAM Form 219; also presented in Figures B-1 to B-14, Appendix B) were very similar to those of the Subjective Fatigue Checkcard.

TABLE 1. USAFSAM VOLANT GALAXY: FLYING TIME FOR AIRCRAFT COMMANDERS (A/C) AND COPILOTS (CP) ON USAFSAM OBSERVED MISSIONS

		Total flying time (hr)	C-5A flying time (hr)
Test missions			
Mission 1	A/C[a]	2718	744
	CP	2596	191
Mission 2	A/C	9250	1550
	CP	2200	277
Mission 3	A/C	2900	700
	CP	3050	145
Mission 4	A/C[b]	2523	802
	CP	2149	345
Control missions			
Mission 5	A/C[b]	2523	802
	CP	2400	560
	CP	2600	340
Mission 6	A/C	3400	450
	CP[a]	2718	744
Mission 7	A/C	5950	2400
	CP	4480	3280

[a] The A/C on mission #1 was also the CP on mission #6.

[b] The A/C on mission #4 was also the A/C on mission #5.

For the 36 crewmen studied over the 7 missions, the average within-subject Pearson product moment correlation coefficient (r) between the 2 fatigue metrics was -0.89 (Table 2).

TABLE 2. USAFSAM VOLANT GALAXY: MEAN WITHIN-SUBJECT r-VALUES FOR SUBJECTIVE FATIGUE RESPONSES TO THE CREW STATUS CHECKCARD AND THE SUBJECTIVE FATIGUE CHECKCARD

	r-value
Four test missions	-0.902 (15/16)[a]
Three control missions	-0.879 (18/20)
Seven missions combined	-0.889 (33/36)

[a]Ratio of crewmen having significant ($p < .01$) correlations between their responses to the two checkcards.

During the test missions, the 8 pilots responded to the Subjective Fatigue Checkcard a total of 102 times. Scores of 7 or lower, indicating severe fatigue, were reported on 6 occasions (5.9%). The 8 flight engineers also reported scores of 7 or less in 3 out of 102 instances (2.9%). All 9 of these scores occurred at the end of a mission leg, after landing. During the control missions, the 7 pilots reported a Subjective Fatigue Checkcard score of 7 or less a total of 6 out of 105 times (5.7%); the 8 flight engineers, 11 out of 102 (10.8%); the 5 navigators, 7 out of 65 (10.8%). Of these 24 scores indicating severe fatigue, 20 (83%) occurred at the completion of a leg after landing.

The highest fatigue response to the Crew Status Checkcard was 6; scores of 7 were never reported during any of the 7 missions. Of 230 responses by the test mission pilots, a score of 6 occurred 7 (3%) times. Of 217 responses by the test mission flight engineers, 3 (1.4%) were scores of 6. The control mission pilots reported a Crew Status Checkcard fatigue score of 6 in 10 out of 223 instances (4.5%); the flight engineers in 8 out of 238 (3.4%); the navigators in 7 out of 138 (5.1%). As with the data for the Subjective Fatigue Checkcard, most of these Crew Status Checkcard scores indicating notable fatigue were reported at the end of a leg, either during the final few hours airborne or just after landing: 9 of 10 for the test missions; 20 of 25 for the control missions.

Although the control missions differed from the test missions in number, crew composition, and itinerary, statistical comparisons of each of the checkcard responses were tenable after calculating overall mean scores for each

mission for 3 subsets of data: after takeoff-from-Travis AFB; after landing-at-Travis AFB; and the average of scores following other-significant-mission-events (other takeoffs, other landings, and aerial refuelings). For the landing-at-Travis AFB data subset, it was necessary to substitute the landing at Dyess AB for mission #2 and the landing at McChord AFB for mission #6, as valid data were not collected after these landings on these missions. The means of the pilots' scores alone (Table 3) and the pilots' and flight engineers' scores combined (Table 4) were statistically analyzed for each subset. One-tailed t-tests were used to compare test missions versus control missions, as it was assumed that if there was any difference between 5-man and 4-man crews, having no navigator would result in greater fatigue. However, none of the t-tests detected any statistically significant ($p<.05$) differences in the responses to either of the fatigue surveys during test missions versus control missions.

Workload Estimates

Pilots--Mean workload scores are presented for each mission in the lower panels of Figures B-1 to B-14, Appendix B. For both test and control missions, maximum workload estimates reported by the pilots seldom exceeded a score of 5 ("pressed, very busy but able to keep up"). Of 229 workload responses reported by the [illegible] during the 4 test missions, 16 (7%) were scores of 5 and 21 (9.2%) were scores of 5, 6, or 7. Of 226 workload responses reported by the 7 pilots during the 3 control missions, 24 (10.6%) were 5 and 26 (11.5%) were 5 or 6. There were no workload scores of 7 reported during the control missions. Workload scores of 5 or more were usually reported in association with takeoffs and landings: in 17 of the 21 instances during test missions; in 13 of the 26 instances during control missions. During preflight preparations, pilot workload estimates exceeded a score of 4 on only 2 occasions; a 6 was reported during a mission #2 preflight and a 5 was reported during a mission #7 preflight. During cruise conditions, "manageable" and "easy-to-keep-up" workloads were typically reported by both the test and control pilots.

An indicator of intense cockpit activity was the occurrence of both on-duty pilots simultaneously reporting workload scores of 5 or more. Eight such instances occurred [illegible]: in 4 cases both pilots reported scores of 5; a 5 and 6 combination occurred in 3 cases; and scores of 6 and 7 were paired once (Table 5). Four of the simultaneous pilot reports of high workload occurred during the test missions, and another 4 occurred during the control missions. Each of the 8 instances of both pilots simultaneously reporting high workload occurred in association with a takeoff or a landing. Inflight emergencies involving landing gear retraction problems occurred in conjunction with 2 of these takeoffs (missions #2 and #6). Tanker rendezvous occurred immediately after another 2 of these takeoffs (missions #1 and #4).

A total of 5 workload scores of 6 or 7 were reported by pilots during the 4 test missions. One score of 6 was reported by the mission #1 copilot during tanker rendezvous and aerial refueling immediately after takeoff from Travis AFB. Simultaneously, the aircraft commander reported a workload score of 5. The only instance over all 7 missions of a 6-workload score occurring while on

TABLE 3. USAFSAM VOLANT GALAXY: SUMMARY OF PILOTS' CHECKCARD SCORES (TEST VS. CONTROL MISSIONS)

Subjective Fatigue[a] (SAM Form 136)

	Test			Control		
	N	$\overline{X}$	SD	N	$\overline{X}$	SD
Takeoff-Travis	2	12.00	2.830	2	13.20	1.650
Other-Events	4	9.95	0.504	3	10.48	3.940
Land-Travis	3	10.00	3.500	1	9.50	—

Subjective Fatigue[b] (SAM Form 219)

	Test			Control		
	N	$\overline{X}$	SD	N	$\overline{X}$	SD
Takeoff-Travis	4	3.75	0.957	3	3.72	0.948
Other-Events	4	3.93	0.294	3	3.96	0.493
Land-Travis	4	4.25	1.555	3	5.17	0.289

Workload Estimate[c] (SAM Form 219)

	Test			Control		
	N	$\overline{X}$	SD	N	$\overline{X}$	SD
Takeoff-Travis	4	4.75	0.646	3	3.78	0.631
Other-Events	4	4.15	0.480	3	3.79	0.473
Land-Travis	4	3.75	0.646	3	3.72	0.948

[a]Scale range of 0-20; lower scores indicate greater fatigue.

[b]Scale range of 1-7; higher scores indicate greater fatigue.

[c]Scale range of 1-7; higher scores indicate greater workload.

TABLE 4. USAFSAM VOLANT GALAXY: SUMMARY OF PILOTS' AND FLIGHT ENGINEERS' WORKLOAD SCORES (TEST VS. CONTROL MISSIONS)

Subjective Fatigue[a] (SAM Form 136)

	Test			Control		
	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Takeoff-Travis	2	13.10	1.590	2	14.00	1.410
Other-Events	4	[illegible]	0.632	3	10.70	0.833
Land-Travis	[illegible]	[illegible]	3.270	1	7.20	—

Subjective Fatigue[b] (SAM Form 219)

	Test			Control		
	N	$\bar{X}$	[illegible]	N	$\bar{X}$	SD
Takeoff-Travis	4	[illegible]	0.595	3	2.77	0.666
Other-Events	4	[illegible]	0.400	3	3.75	0.399
Land-Travis	4	4.4?	1.318	3	4.69	0.700

Workload Estimate[c] (SAM Form 219)

	Test			Control		
	N	$\bar{X}$	SD	N	$\bar{X}$	SD
Takeoff-Travis[d]	[illegible]	[illegible]	0.239	3	3.37	0.322
Other-Events[d]	4	3.46	0.139	3	3.06	0.272
Land-Travis	4	3.3?	0.658	3	3.42	0.684

[a] Scale range of 0-20; lower scores indicate greater fatigue.

[b] Scale range of 1-[illegible]; higher scores indicate greater fatigue.

[c] Scale range of [illegible]; higher scores indicate greater workload.

[d] Mean workload estimates significantly greater for the test missions than for the control missions ($p<.05$; one-tailed t-test).

the ground was reported by the mission #2 copilot during preparations for departing RAF Mildenhall. Subsequent to the mission #2 takeoff from RAF Mildenhall, a landing gear retraction malfunction occurred. The copilot reported scores of 7 and 6 during the 2 hours encompassing the takeoff and resolution of the gear problem. The aircraft commander simultaneously reported workload scores of 6 and 4, respectively. The copilot failed to make a required air-traffic-control radio check during this emergency.

The only 2 pilot workload scores of 6 recorded during the control missions were both reported by the mission #6 aircraft commander. One 6 was associated with a landing gear retraction problem which required returning to base immediately after takeoff. Simultaneously with the aircraft commander's response of a 6, the copilot and navigator each reported scores of 5. The other workload score of 6 was reported in association with another landing.

Flight engineers--Across all 7 missions, workload scores of 5 were the highest reported by the flight engineers. Of 217 workload responses by the 8 flight engineers on the 4 test missions, workload scores of 5 were reported only twice (0.9%): once during a landing on mission #1 and once during a takeoff on mission #3. Workload scores of 5 were reported 8 out of 247 times (3.2%) by the 8 flight engineers who flew the 3 control missions: 3 times each during missions #5 and #7, and twice during mission #6. Five of these 8 scores were reported in association with takeoffs and landings and 2 occurred during preflight preparations. The only instance of simultaneous flight engineer reports of high workload occurred during the mission #7 aerial refueling, when 2 of 3 engineers reported scores of 5 while the pilots reported a 3 and a 4. As summarized in Table 5, flight engineer workload scores of 5 were never reported in association with any of the simultaneous pilot reports of high-to-unmanageable workloads.

Navigators--The 5 navigators who actively participated in the 3 control missions reported a total of 142 workload scores, of which only 3 (2.1%) were greater than a score of 4. Two workload scores of 5 were reported by the onduty navigator on mission #5 while in European airspace and on approach to Rhein Main AB. Another workload score of 5 was reported by the mission #6 navigator during the gear retraction problem following takeoff from Yokota AB (see Table 5).

Statistical analysis--The workload scores from the pilots and the flight engineers were subjected to the same data reduction procedures and t-test analyses as were the subjective fatigue scores (Tables 3 and 4). For the pilot and flight engineer scores combined, significantly higher ($p<.05$) workload scores were reported by the test mission crews than by the control mission crews for 2 of the 3 subsets of data: takeoff-from-Travis AFB, and other-significant mission-events. Although statistically different, the practical significance of these findings may be questionable, as the absolute mean values of both the test- and control-mission scores indicated manageable workloads. However, for each of these subsets of data, the statistical difference between the mean test- and control-mission scores does reflect a slightly greater frequency of moderate and high workload reports during the test missions.

TABLE 5. [illegible] SIMULTANEOUS PILOT REPORTS OF HIGH WORKLOAD

Event	Crew Position[a]					
	A/C	CP	N	FE_1	FE_2	FE_3
Takeoff-Refuel, Travis AFB Mission #1	[illegible]	6		3	2	
Takeoff-Gear Problem; RAF Mildenhall; Mission #2	[illegible]	7		3	3	
Takeoff-Rendezvous; Travis AFB; Mission #4	[illegible]	5		3	3	
Land; Dover AFB; Mission #4	[illegible]	5		4	3	
Land; RAF Mildenhall, Mission #5[b]	[illegible]	5	3	4	2	
Land; Yokota AB, Mission #[illegible]	[illegible]	5	4	4	1	3
Land; Yokota AB; Mission #6	[illegible]	5	4	2	1	2
Takeoff-Gear Problem; Yokota AB; Mission #[illegible]	6	5	5	4	3	1

[a]A/C, aircraft commander; CP, copilot; N, navigator; FE, flight engineer.

[b]A third pilot reported a 2; two additional navigators each reported a 1.

Pilot Activities

The time devoted by the pilots to selected cockpit activities was successfully documented on one of the test missions (#1) and two of the control missions (#5 and #7). The data from the other missions could not be reliably

evaluated because of equipment malfunction. The percent of time devoted by the aircraft commander and the copilot to manual flight control, autopilot control, INS operation, and the time only 1 pilot was seated in the cockpit is presented in Table 6. The small sample size of 3 missions and the complicating factor of an extra pilot on mission #5 restrict interpretation of these data. The single-pilot category is potentially very enlightening in relation to the pilots' ability to acquire inflight rest on 4-man versus 5-man crews. While comparison of this category for missions #4 and #7 suggests a difference in favor of 5-man crews, much more data would be required for either statistical or operational significance to occur.

TABLE 6. USAFSAM VOLANT GALAXY: PERCENT OF AIRBORNE TIME DEVOTED BY PILOTS TO SELECTED COCKPIT ACTIVITIES (A/C: AIRCRAFT COMMANDER; CP: COPILOT)

	Mission		
Activity	Test #4	Control #5[a]	Control #7
A/C Manual Control	12	9	13
CP Manual Control	1	2	2
A/C Auto Pilot	76	51	64
CP Auto Pilot	11	38	21
A/C INS Operation	4	4	[illegible]
CP INS Operation	5	7	4
Single Pilot On-duty	23	18	35

[a]Mission #5 results confounded by presence of 3 active pilots.

DISCUSSION

The subjective fatigue and workload data collected and evaluated by USAFSAM do not provide a definitive conclusion as to the feasibility of 4-man cockpit crews safely performing airlift missions on triple-INS-equipped C-5A aircraft. That the triple INS reduces the need for traditional onboard navigational skills is undeniable, but the navigator contributes to mission success and mission safety in other ways. His training provides unique skills during radar interpretation and flight planning; and he contributes to the skilled manpower available for other duties such as scanning, spotting, system-problem resolution, radio communication, and coping with emergencies.

[illegible] which
[illegible] loads
[illegible] the
[illegible]

[illegible] under
[illegible]

but would also add several minutes to the duty day. To save this time, as the 16-hour crew duty day was very close to expiration, the onboard navigator/safety observer interceded and, using the navigator-station radar, directed the aircraft through the cells without incident. Moderate-to-severe thunderstorms were also present in the Yokota AB area during a daytime departure of one of the control missions (#7). Based on his radar interpretation, the navigator's recommendation of a best course was solicited and followed by the highly experienced aircraft commander. These observations do not indicate that pilots cannot interpret and use the radar; they do indicate that the pilots recognize the superior training and skills of the navigator and the superior quality of the radar at the navigator's station compared to that at the pilots' stations. A large part of the navigation and radar skills of most C-5A aircraft commanders have been acquired over time while flying with navigators. Given 4-man cockpit crews, less experienced and future C-5A pilots will not receive this on-the-job training. Installation of better and simpler-to-use radars at the C-5A pilots' stations would enhance the feasibility of the 4-man cockpit crew. Regardless, implementation of the 4-man concept would require improved radar training of pilots.

An evaluation similar to VOLANT GALAXY has been conducted previously by the Aeronautical Systems Division to assess the feasibility of eliminating the navigator on dual-INS-equipped KC-135 aircraft (3). The test crews consisted of an aircraft commander, copilot, and boom operator. The copilot assumed the navigator duties. Questionnaires and inflight observation of the crewmen were used to assess crew workload during several types of aerial refueling missions. Findings and recommendations were similar to those for VOLANT GALAXY. During critical phases of the missions, excessively high workloads occurred which, in some cases, constituted safety hazards. The severe task loading resulted in the deletion or postponement of many normal duties, usually communication and radar tasks. On some occasions, test mission integrity was maintained only through active assistance from the navigator/safety observer. Recommendations included redesign of cockpit configuration, installation of an improved radar, and increased training in radar operation and interpretation. In a subsequent study (2), an additional boom operator, designated a Flight Systems Operator (FSO), was assigned as a fourth man to the KC-135 test crews. The FSO was trained in the fundamentals of navigation, radar scope interpretation, INS operation, and rendezvous procedures. His primary duties were to operate and interpret the radar scope and to relieve the copilot of navigation duties during periods of peak workload. With this crew complement overload situations did not occur and refueling operations were feasible and safe.

It should be borne in mind that the VOLANT GALAXY OT&E was conducted under peacetime conditions. Currently, the missions selected for the test are usually flown by augmented crews. During the test missions, they were flown by basic crews (without a navigator) only for the purposes of the OT&E. These missions were selected for the OT&E because they involve long legs and aerial refuelings. Barring delays, these legs can be completed within the basic 16-hour crew duty day. However, due to the current low C-5A flying requirement, the manpower exists to augment these missions. The augmentation better assures timely, safe, and legal mission completion even if some delays occur, as the augmented crew duty day is 24 hours. Training and check-ride requirements also contribute to increasing crew size.

During a crisis or wartime situation, such as the 1973 Mid-East War, C-5A utilization rate will increase dramatically and crewmen will not be available to serve as augmentees on missions not requiring augmentation. Most missions will likely involve long legs, aerial refuelings, and even multiple aerial refuelings. The airlift routes flown may be unique, perhaps being traversed by MAC crews for the first time. The missions may require precise navigation to avoid overflying neutral or hostile territories. Crew rest and recovery regulations may be waived. Crew rest facilities may be meager or nonexistent. During the 1973 Mid-East War, the limit of 125 hours flying time per month was waived, premission and postmission crew rest were often cut short, and crews literally slept on tables and lawns while staging at Lajes Field, Azores (10). Conditions such as these sharply demonstrate the differences between commercial and military transport operations. These conditions reduce the psychological and physiological resources of each crewman, resulting in fatigue, which impacts on each crewman's workload capacity. Given such mission scenarios and current C-5A radar equipment, the inclusion of a navigator as a member of the C-5A cockpit crew seems to be desirable. The more specialized and overtrained a crewman is for the duties of his position, the less effect fatigue will have on the speed and accuracy of his performance (1, 5, 12).

Two human engineering problems relating to the locations of the pilot's INS and the copilot's radar scope deserve attention. Sunglare can completely "washout" the INS digital readouts located in the center console. When this occurs, the pilots usually "cup" the readout with their hand so as to project a shadow. A quick-fix would be snap-on sunshields for use when necessary. Regardless of this problem, a remote indicator of the INS readout unit should be installed in each pilot's instrument panel next to the INS "leg alert" signal light. This location omits the requirement to turn the head to read the output and keeps the INS output in the pilot's primary field of view. The location of the copilot's radar scope at his right side makes its use very difficult and fatiguing. If the 4-man cockpit crew concept is implemented, the copilot's radar scope must be moved to the forward instrument panel. Very similar human engineering problems were reported during the KC-135 test missions.

Although not specific to the [illegible], [illegible] one of the many irritants which [illegible] MAC crew as they progress through a mission. As witnessed by [illegible] personnel [illegible] and other operational tests, some crew rest facilities [illegible] offer little protection against light and noise, particularly when crew rest occurs during local daytime hours. Pre- and postflight [illegible] unavailable, and some flight snacks and box lunches [illegible]. Perhaps the most often-heard crew complaint relates to the [illegible] time required to check into billeting offices, as this [illegible] the allotted crew-rest time. Instances of [illegible] base billeting office are not uncommon. It would seem that much of the paperwork responsible for these delays could be completed and processed while the mission is inbound. When contract housing is used, a great deal of time could be saved by a system which allowed the crew to be transported directly from the aircraft to the contract quarters. [illegible] contributes significantly to the accumulation of crew stress and fatigue. Reduction of the C-5A crew size would make the availability of [illegible] crew rest and [illegible] facilities even more important [illegible].

CONCLUSIONS AND RECOMMENDATIONS

1. The subjective fatigue [illegible] data collected [illegible] by USAFSAM do not, by themselves, permit a definitive conclusion as to the feasibility of 4-man cockpit crews successfully performing required missions in triple-INS-equipped C-5A aircraft. [illegible] the data obtained, discussions with crewmen, subjective impressions, and [illegible] workloads recorded during the few emergencies and [illegible], a conservative recommendation against implementing [illegible].

2. If the concept were to be implemented, it should await installation of a better and less complex radar [illegible] and [illegible] instrument panels. Implementation will require more extensive radar training and related experience for pilots.

3. The operational conditions of wartime should be considered in any decision to remove the navigator from the C-5A crew complement. The availability of an additional skilled crewmember [illegible] provides more performance insurance during periods of extreme [illegible] such as encountered during wartime or serious emergencies.

4. Human engineering [illegible] exist with the present locations of the copilot's radar scope [illegible] pilot's INS control/display units. [illegible] radar scope can be corrected by relocating it on the copilot's forward instrument panel. The INS [illegible] problems can be corrected by [illegible] repeaters [illegible] displays in each pilot's primary field of view.

5. [illegible] crews [illegible] exposed to several [illegible] which contribute [illegible] fatigue and decreased morale. A [illegible] improve [illegible] and the efficient movement [illegible].

REFERENCES

1. [illegible] Literature [illegible].

2. [illegible] crew on a [illegible]-135 aircraft [illegible].

3. Geiselhart, R., et al. [illegible] study of task loading [illegible] crew on a KC-135 aircraft. [illegible] 1976.

4. Harris, [illegible] A., et al. Performance and fatigue in experimental double-crew transport missions. Aerospace Med. [illegible].

5. Hartman, B. O. Management of irregular rest and activity. AGARD Lecture Series No. 105. Sleep, wakefulness, and circadian rhythm, 1979.

6. Hartman, B. O., et al. Psychobiologic aspects of double-crew long-duration missions in C-5 aircraft. Aerospace Med 45:1149-1154 (1974).

7. Headquarters, Military Airlift Command. C-141 in-flight crew rest final report. MAC test 15-19-79, Scott AFB IL, Aug 1979.

8. Pearson, R. G., and G. E. Byars, Jr. The development and validation of a checklist for measuring subjective fatigue. SAM-TR-56-115, Dec 1956.

9. Storm, W. F., and P. J. Dowd. Aircrew fatigue and the C-5A double-crew Blue/Gold concept. Unpublished SAM letter rerort, Nov 1977.

10. Storm, W. F., et al. MAC Mid-East resupply operation (Oct-Nov 1973): A retrospective study. SAM-TR-75-19, Jun 1975.

11. USAF Airlift Center. VOLANT GALAXY final report: C-5 four-man cockpit crew operational test and evaluation. MAC project 5-40-79, Pope AFB NC, Nov 1979.

12. Woodward, D. P., and P. D. Nelson. A user oriented review of the literature on the effects of sleep loss, work-rest schedules, and recovery on performance. ONR Report ACR-206, Dec 1974.

APPENDIX A

SCHEDULED ITINERARIES AND
MISSION LOGS

TABLE A-1. USAFSAM VOLANT GALAXY MISSION #1
Westbound Test Mission/10-13 May 1979

Scheduled Itinerary

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				10/2300Z*AR
Yokota	11 + 30	11/1030	16 + 15	12/0245
Osan	2 + 15	12/0500	4 + 15	12/0915
Yokota	1 + 40	12/1055	18 + 15	14/0510
Travis	9 + 20	13/1430		

Mission Log

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				10/2315AR
Yokota	12 + 55	11/1210	17 + 25	12/0535
Osan	2 + 05	12/0740	4 + 20	12/1200
Yokota	1 + 30	12/1330	18 + 00	13/0730
Travis	9 + 20	13/1650		

*All times GMT
AR: Aerial refueling scheduled and successfully completed.

TABLE A-2. [illegible] AND GALAXY MISSION [illegible]
Eastbound Test Mission/14-19 May 1979

Scheduled Itinerary

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				14/2230Z*
Tinker	3 + 00	15/0130	23 + 30	16/0100
Mildenhall	9 + 25	16/1025	24 + 00	17/1025
Dover	8 + 30	17/1855	17 + 15	18/1210
Travis	6 + 00	18/1810		

Mission Log

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				15/0100
Tinker	3 + 00	15/0400	21 + 05	16/0105
Mildenhall	8 + 40	16/0945	24 + 50	17/1035 G
Dover	8 + 30	17/1905	23 + 45	18/1850
Travis	6 + 30	19/0020		

*All times GMT

G: Landing gear retraction malfunction occurred.
Problem corrected inflight [illegible] continued.

TABLE A-3. USAFSAM VOLANT GALAXY MISSION #3
Westbound Test Mission/17-20 May 1979

Scheduled Itinerary

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				17/2300Z*AR
Yokota	11 + 30	18/1030	16 + 15	19/0245
Osan	2 + 15	19/0500	4 + 15	19/0915
Yokota	1 + 40	19/1055	18 + 15	20/0510
Travis	9 + 20	20/1430		

Mission Log

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				17/2315
Hickam	5 + 45	18/0500	17 + 30	18/2230
Yokota	8 + 15	19/0645	20 + 15	20/0300
Osan	2 + 10	20/0510	3 + 40	20/0850
Yokota	1 + 40	20/1030	3 + 05P	20/1335
Travis	9 + 00	20/2235		

*All times GMT
AR: Aerial refueling scheduled, but not successfully completed. Resulted in diversion to Hickam AFB HI.
P: Quick-stop at Yokota AB required augmented crew to legally support extended duty day. A rested pilot joined the crew at Yokota AB and flew most of the return leg to Travis AFB CA. Therefore, data from this leg excluded from USAFSAM analyses.

TABLE A-4. USAFSAM VOLANT GALAXY MISSION #4
Eastbound Test Mission/21-26 May 1979

Scheduled Itinerary

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				14/2230Z*
Tinker	3 + 00	15/0130	23 + 30	16/0100
Mildenhall	9 + 25	16/1025	24 + 00	17/1025
Dover	8 + 30	17/1855	17 + 15	18/1210
Travis	6 + 00	18/1810		

Mission Log

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				21/2155
Tinker	3 + 00	22/0055	44 + 00[M]	23/2055
Mildenhall	8 + 30	24/0525	24 + 20	25/0545
Dover	8 + 25	25/1410	17 + 15	26/0725
Travis	5 + 20	26/1245		

*All times GMT
M: Maintenance problem returned crew to crew rest.

TABLE A-5. USAFSAM VOLANT GALAXY MISSION #5
Eastbound Control Mission/10-14 July 1979

Scheduled Itinerary

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				14/2300Z*
Dover	6 + 00	11/0500	23 + 00	12/0400
Rhein Main	7 + 45	12/1145	5 + 15	12/1700
Mildenhall	1 + 10	12/1810	16 + 20	13/1030
Travis	10 + 20	13/2050		

Mission Log

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				10/2255
Dover	4 + 55	11/0350	41 + 50M	12/2140
Rhein Main	8 + 00	13/0540	5 + 50	13/1130
Mildenhall	1 + 00	13/1230	16 + 35	14/0505
Travis	11 + 25	14/1630		

*All times GMT
M: Maintenance problem returned crew to crew rest.

TABLE A-6. USAFSAM VOLANT GALAXY MISSION #6
Westbound Control Mission/12-13 July 1979

Scheduled Itinerary

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				12/2015Z*
Elmendorf	4 + 20	13/0035	21 + 25	13/2200
Yokota	7 + 25	14/0525	22 + 20	15/0345
Osan	2 + 00	15/0545	4 + 15	15/1000
Yokota	1 + 40	15/1140	18 + 15	16/0555
Travis	9 + 55	16/1550		

Mission Log

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				12/2255
Elmendorf	4 + 30	13/0325	21 + 10	14/0035
Yokota	7 + 25	14/0800	16 + 00	14/2400
Osan	2 + 00	15/0200	5 + 20	15/0720
Yokota	1 + 40	15/0900	25 + 30	16/1030
Yokota	0 + 35	16/1105[G]	18 + 15	17/0520
McChord	9 + 25	17/1445	2 + 10	17/1655
Travis	1 + 25	17/1820		

*All times GMT
G: Landing gear retraction malfunction required return-to-base; crew returned to crew rest.

TABLE A-7. USAFSAM VOLANT GALAXY MISSION #7
Westbound Control Mission/20-24 July 1979

Scheduled Itinerary

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				19/2300Z*
Yokota	11 + 30	20/1030	17 + 15	21/0345
Cubi	4 + 25	21/0810	4 + 15	21/1225
Clark	0 + 30	21/1255	19 + 35	22/0830
Yokota	4 + 00	22/1230	17 + 55	23/0625
Travis	9 + 50	23/1615		

Mission Log

Station	Airborne (hr+min)	Arrive	Ground (hr+min)	Depart
Travis				20/0025
Travis	0 + 25	20/0050[I]	0 + 30	20/0120[AR]
Yokota	11 + 55	20/1315	18 + 45	21/0800
Clark	3 + 50	21/1150	39 + 15[M]	23/0305
Cubi	0 + 25	23/0330	2 + 20	23/0550
Kadena	2 + 25	23/0815	18 + 05	24/0220
Yokota	2 + 00	24/0420	4 + 35	24/0855
Travis	10 + 45	24/1940		

*All times GMT
I: Airspeed indicator malfunction required return-to-base for replacement.
AR: Aerial refueling scheduled and successfully completed.
M: Maintenance problem returned crew to crew rest.

APPENDIX B

MEAN SUBJECTIVE FATIGUE
AND WORKLOAD RESPONSES

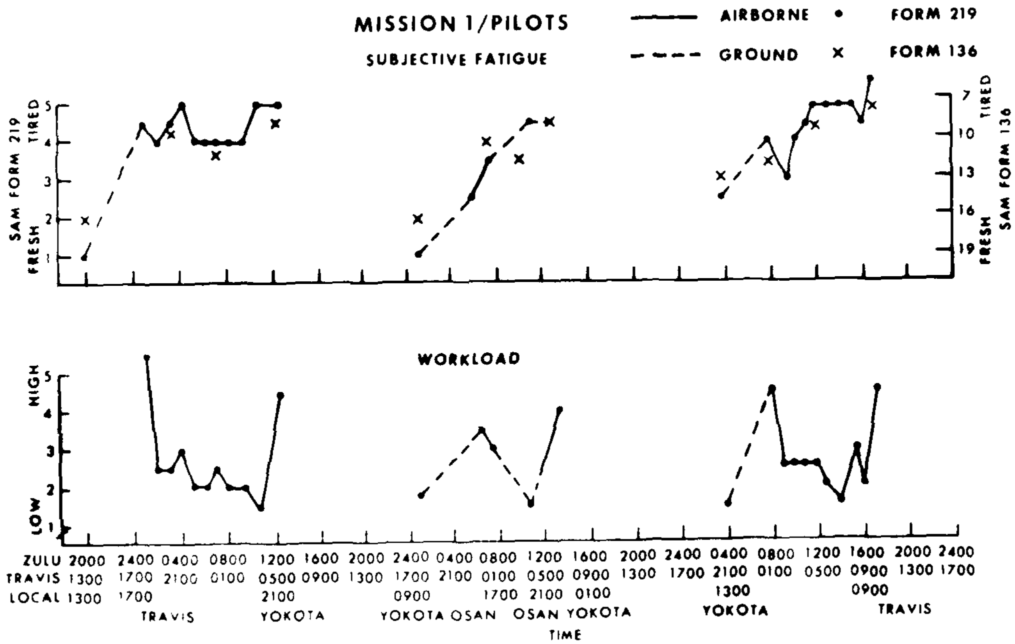

Figure B-1. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-1.

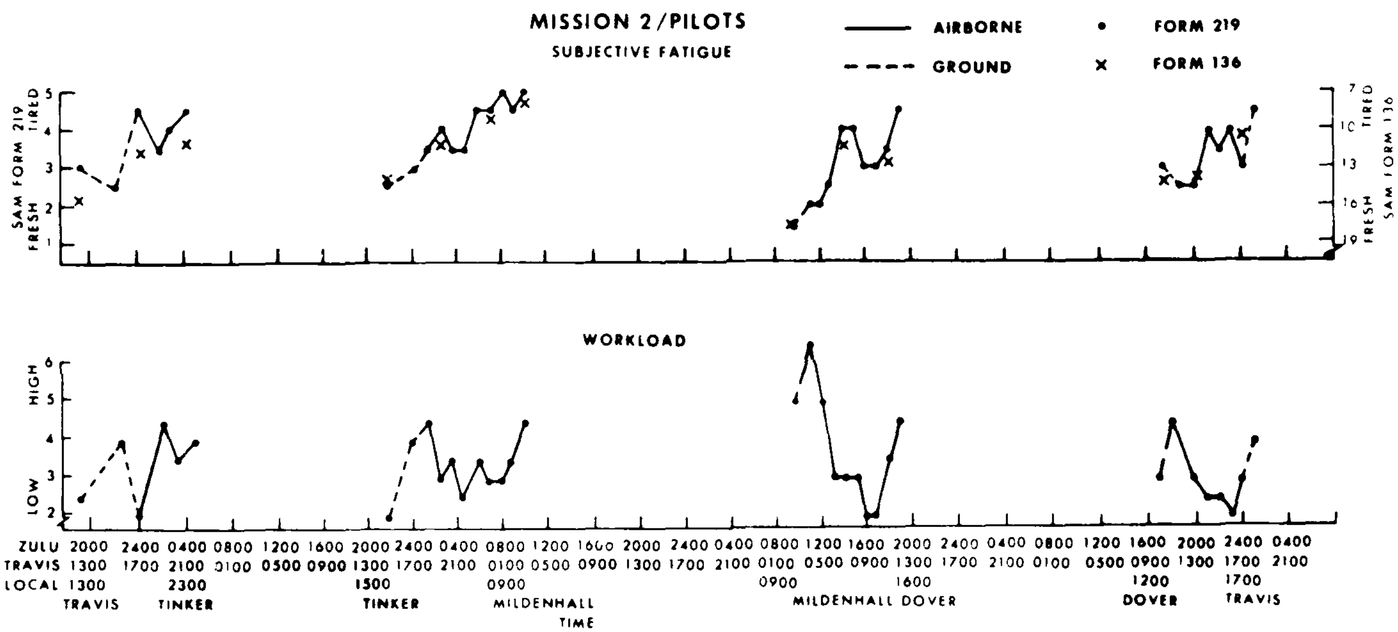

Figure B-2. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-2.

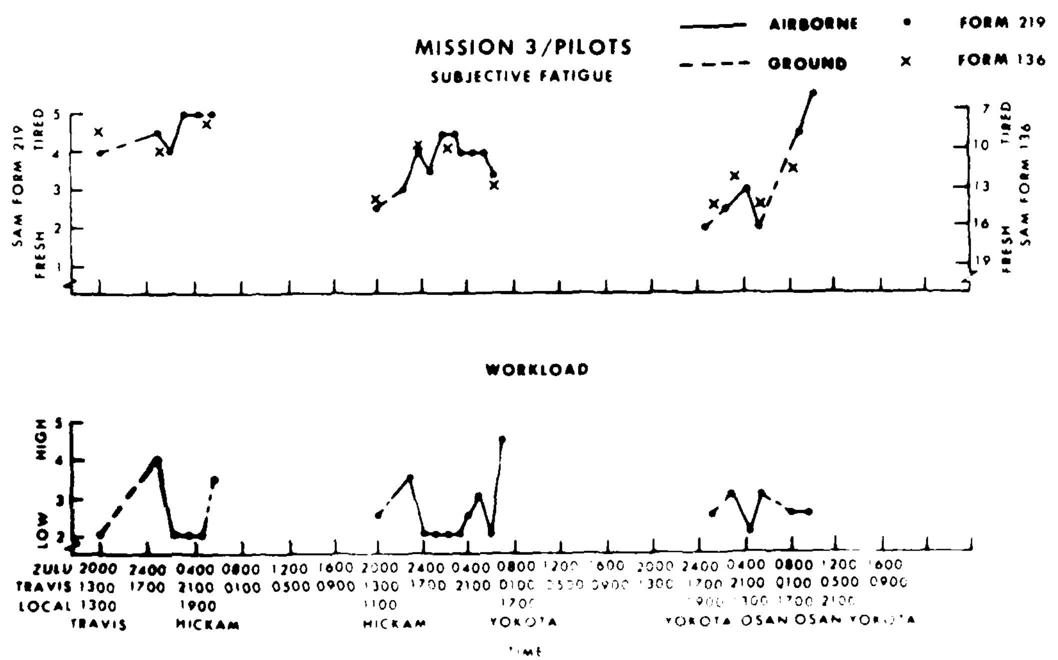

Figure B-3. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-3.

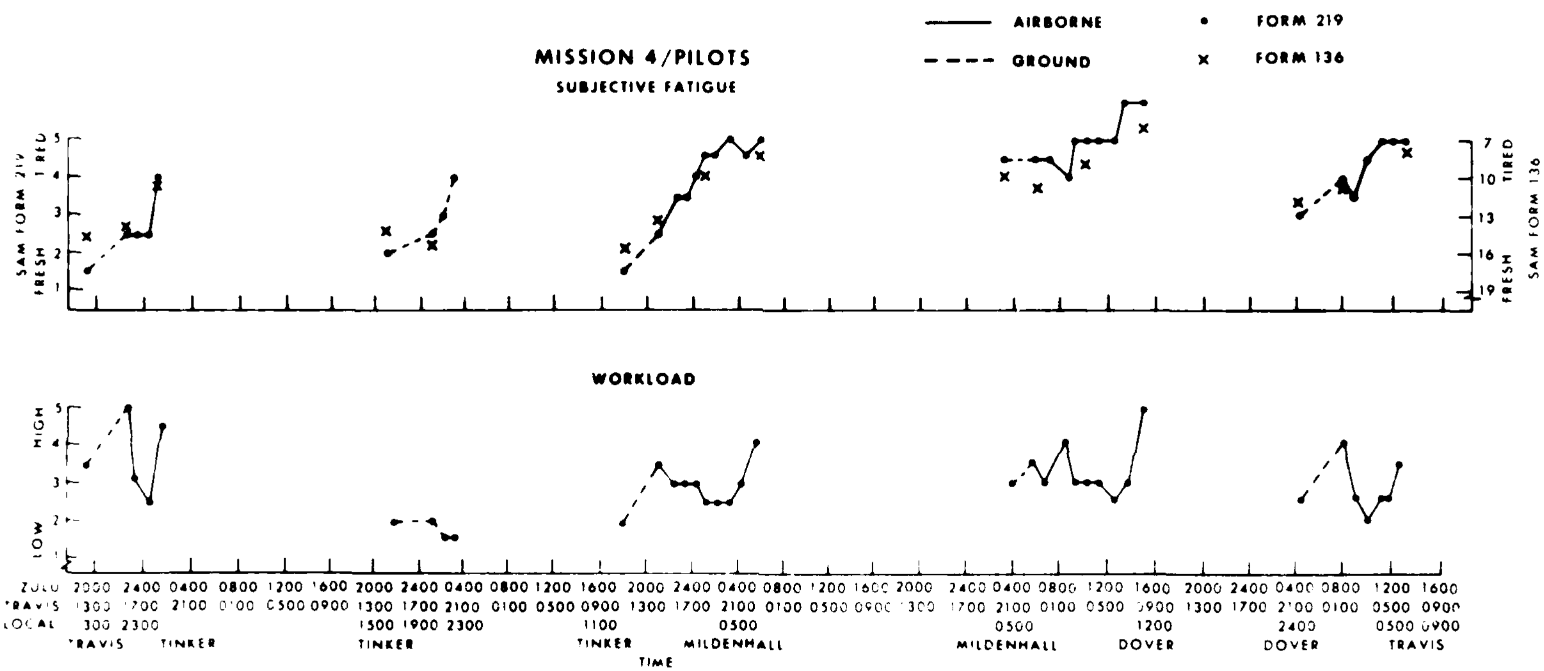

Figure B-4. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-4.

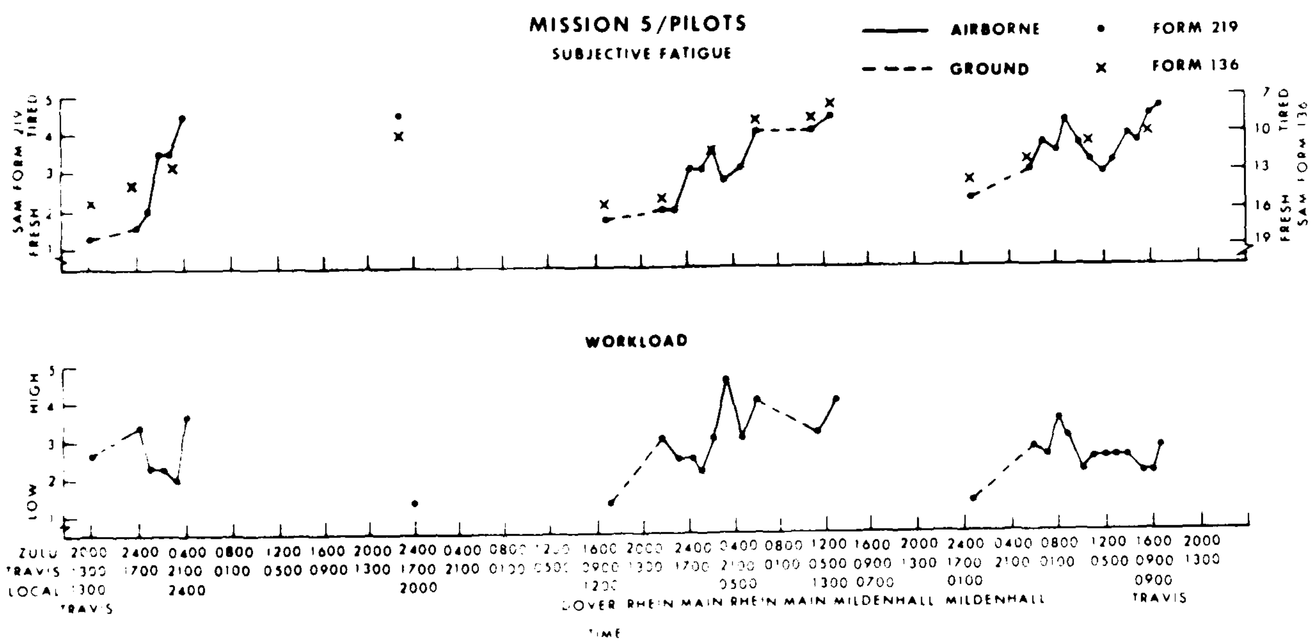

Figure B-5. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-5.

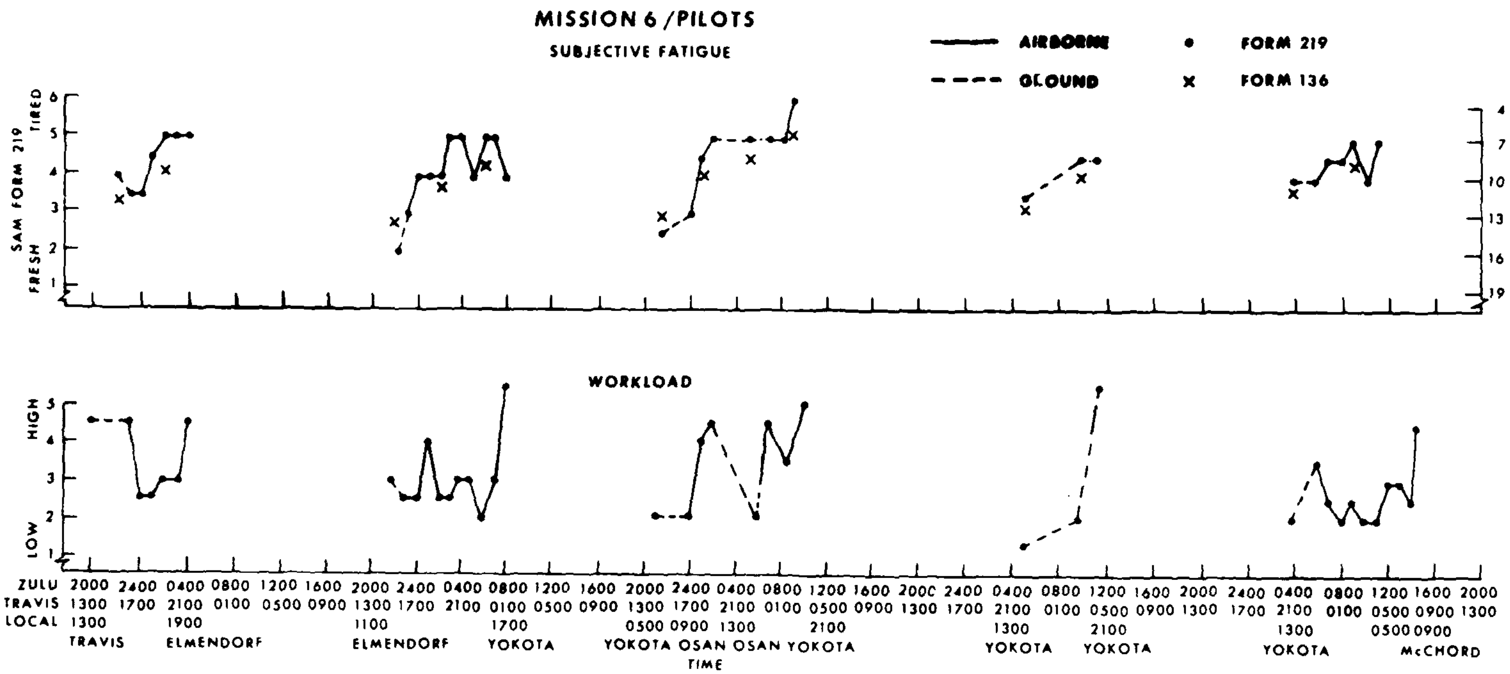

Figure B-6. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-6.

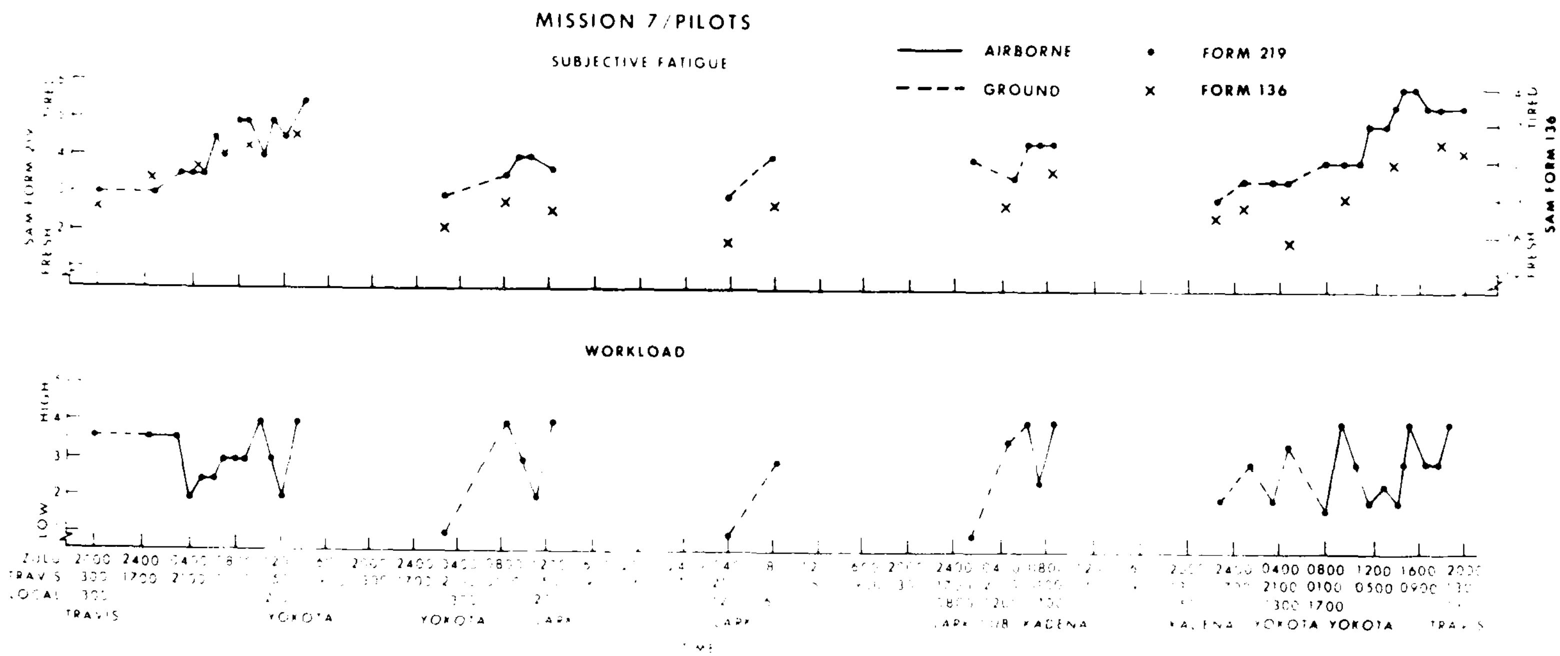

Figure B-7. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-7.

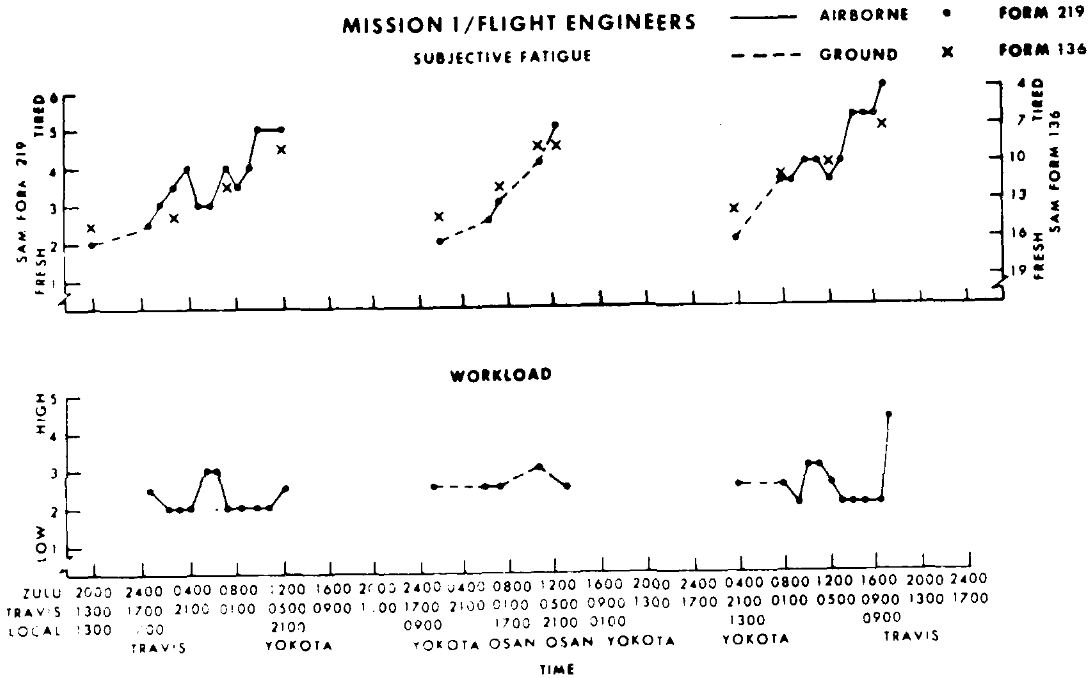

Figure B-8. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-1.

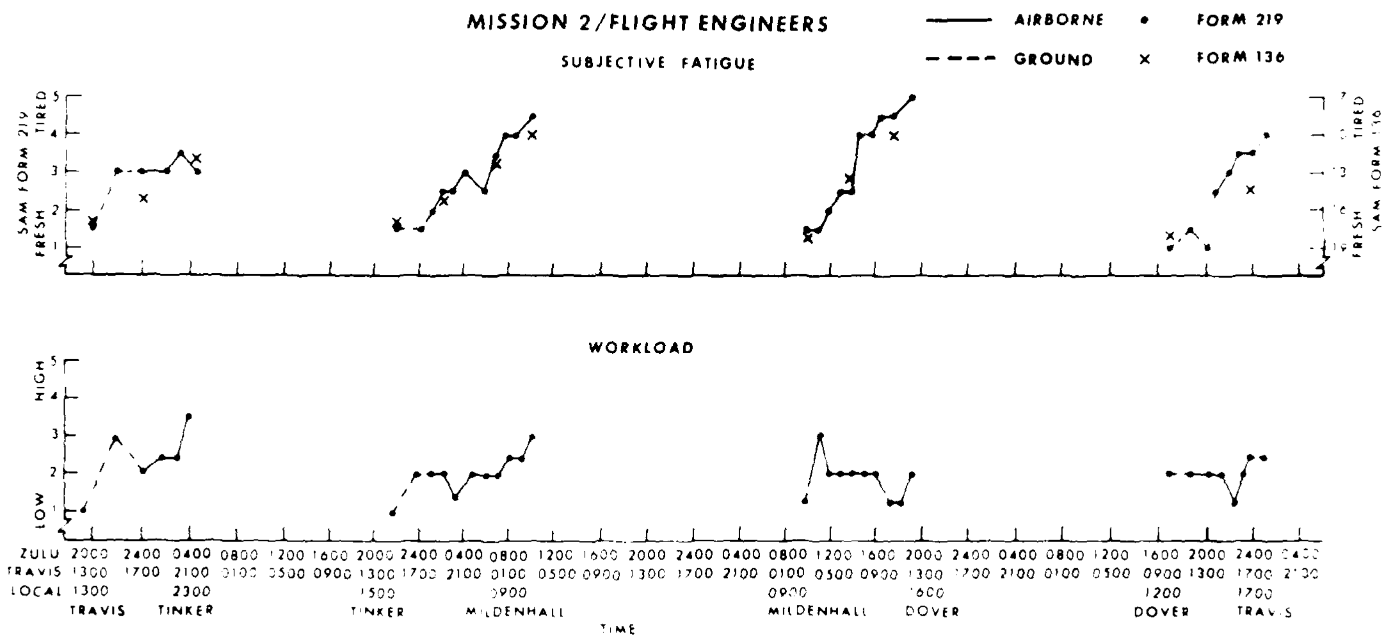

Figure B-9. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-2.

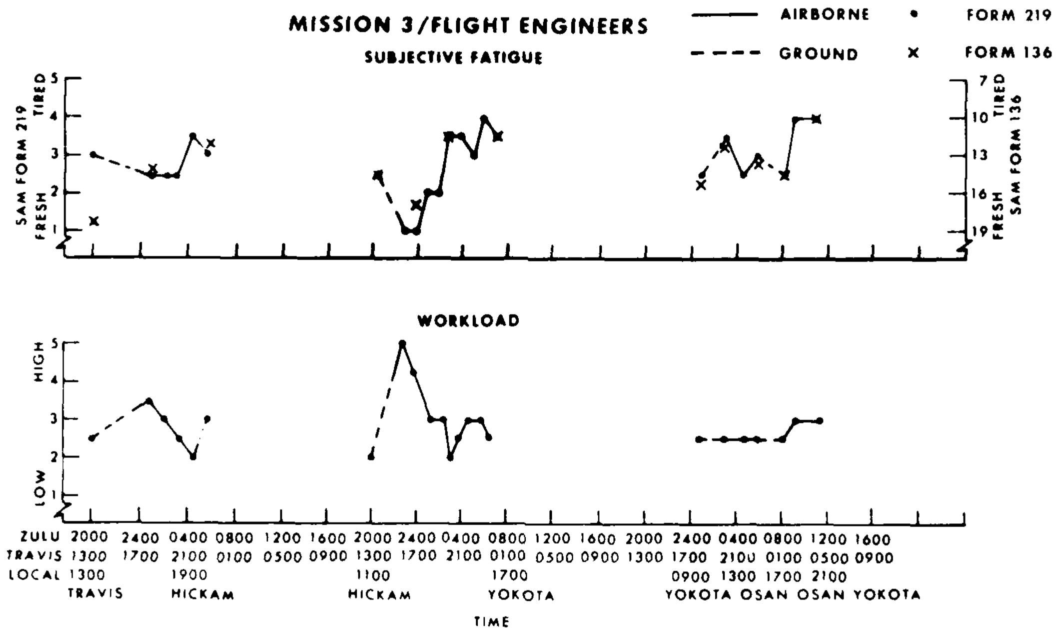

Figure B-10. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-3.

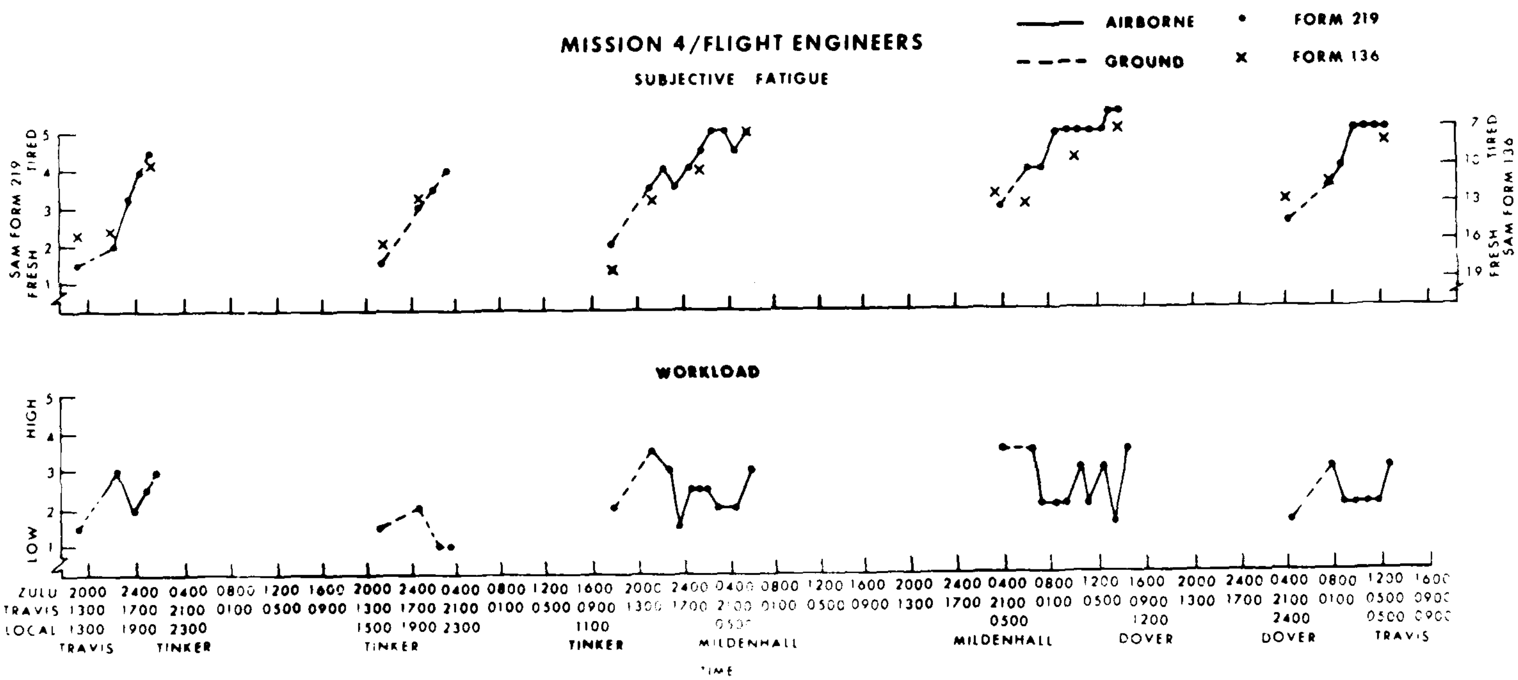

Figure B-11. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-4.

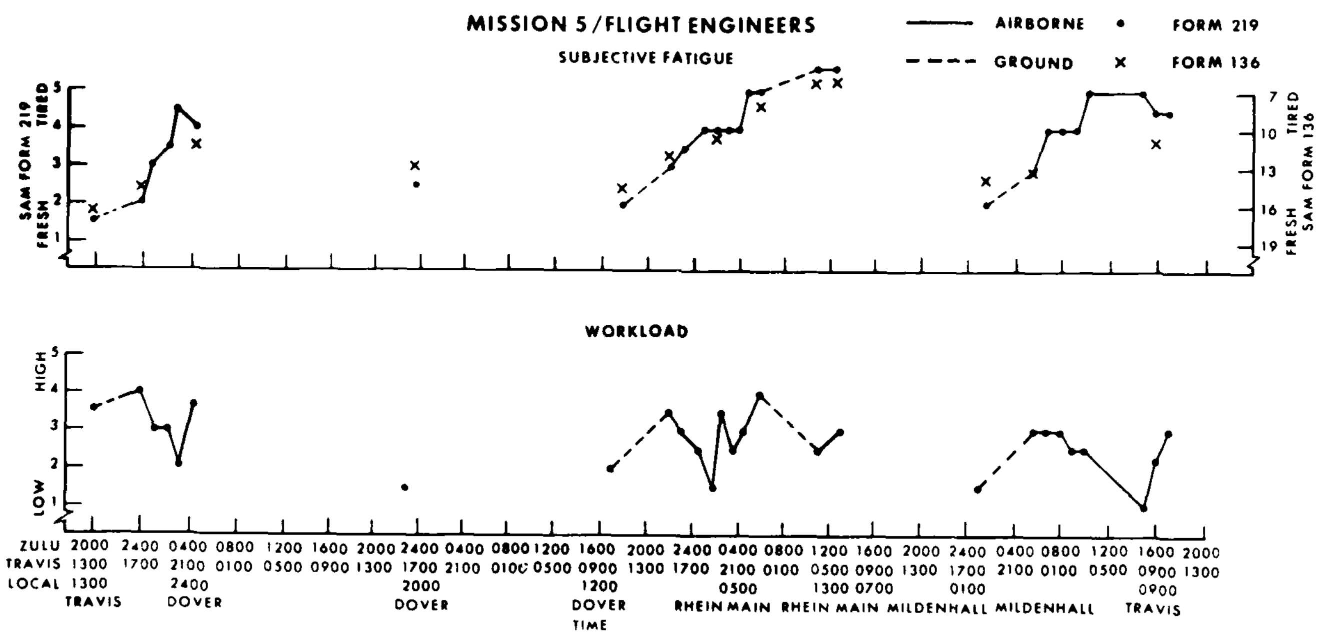

Figure B-12. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-5.

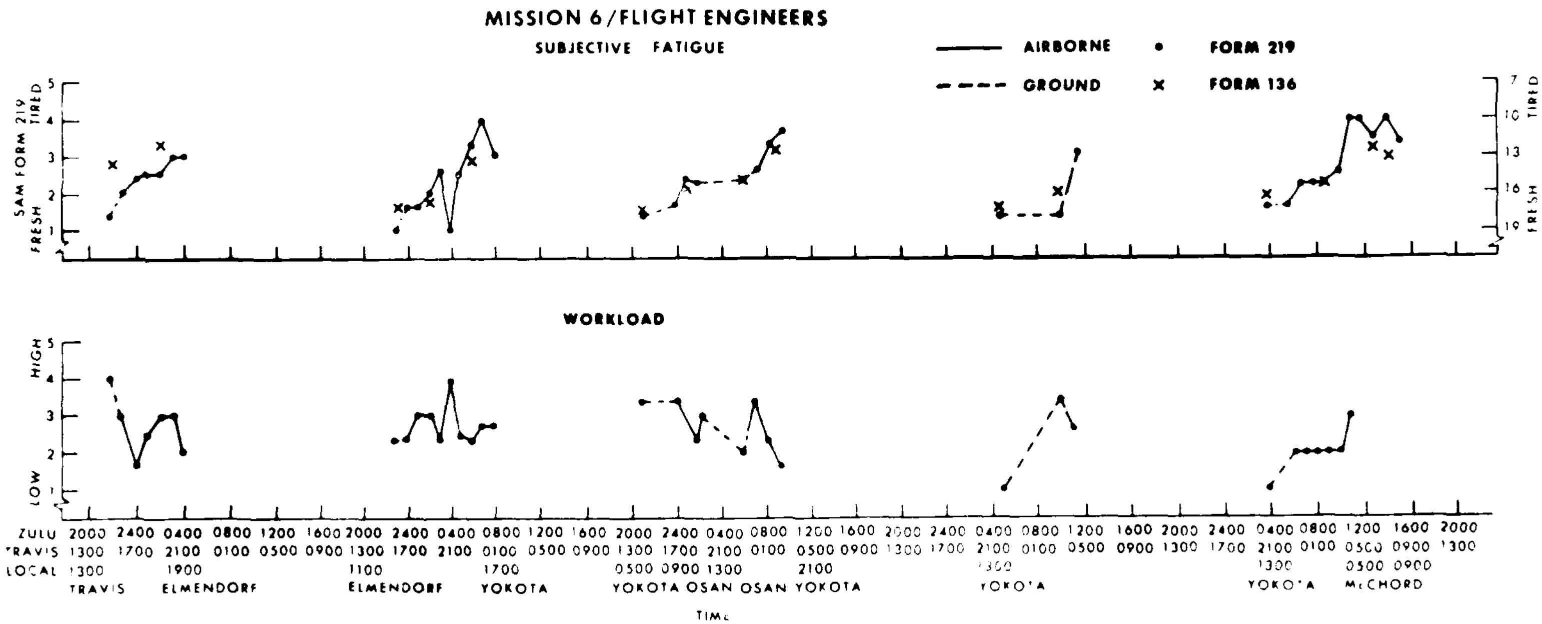

Figure B-13. Mean subjective fatique and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-6.

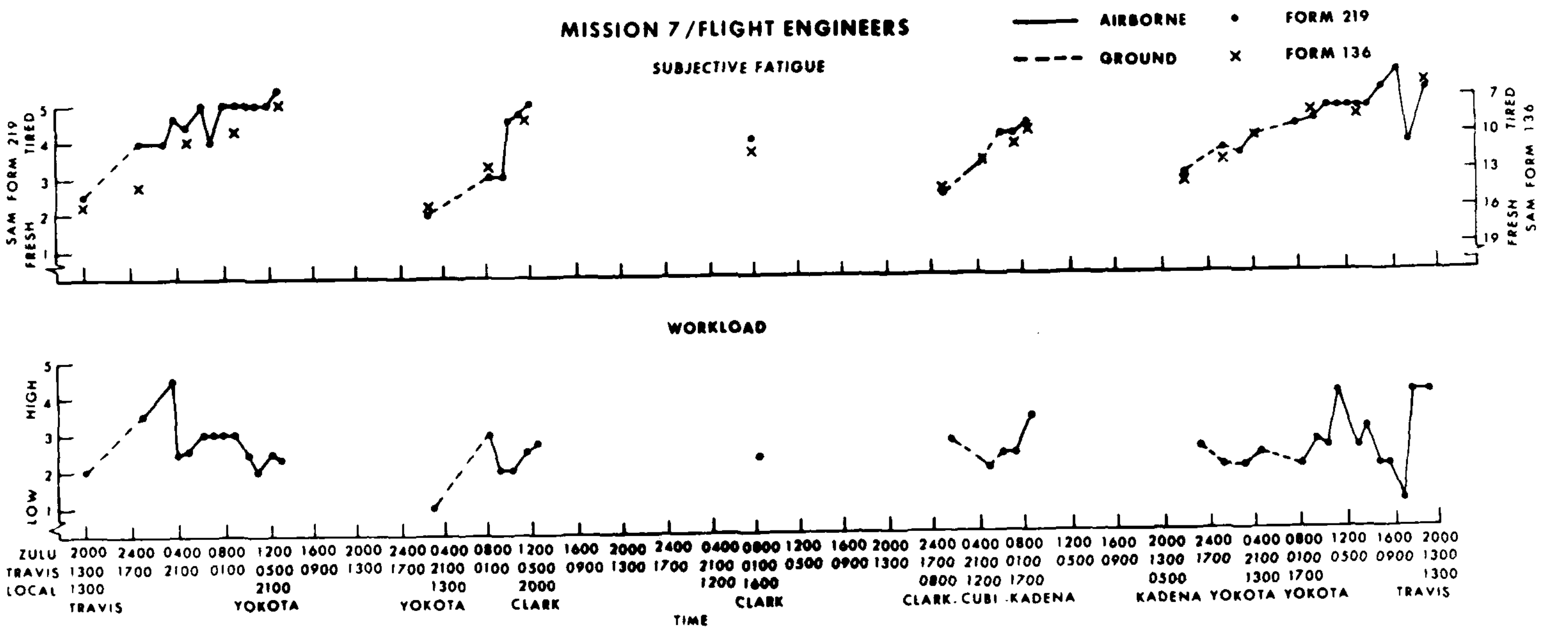

Figure B-14. Mean subjective fatigue and workload responses. The broken and solid lines approximate, respectively, the ground and airborne segments of each leg. The exact times of each takeoff and landing are presented in Table A-7.

DAT

FILM